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**AEROJET
GENERAL**

REPORT NO. RN-S-0050
TO
AEC-NASA SPACE NUCLEAR PROPULSION OFFICE
RADIATION ANALYSIS OF MECHANICAL IRRADIATION TESTS
901 THROUGH 904 (U)



ROCKET ENGINE OPERATIONS - NUCLEAR

NERVA PROGRAM CONTRACT SNP-1 JANUARY 1964

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ABSTRACT

This report contains the results of radiation analyses performed in support of Mechanical Irradiation Tests 901, 902, 903 and 904. Comparisons are made between the calculated test environment and the comparable NERVA flight environment. Comparisons are also made with experimental results in those cases where experimental data were available.

Fast neutron flux and gamma ray dose-rates and integrated doses are reported, as well as the neutron-to-gamma number flux ratio for each component as it appears in NERVA and the GD/FW ASTR test. Gamma heating rates are also presented in the same context.

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for J. D. Stinnett

J. D. Stinnett
NERVA Technical Systems Manager
REON

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I INTRODUCTION

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I. INTRODUCTION

This report describes the results of a radiation analysis of the environment to which mechanical components of the NERVA engine are exposed at the General Dynamics Aerospace Systems Test Reactor (ASTR). Mechanical irradiation tests 901 through 904 are included in this analysis. (See References 1 through 4.)

Neutron and gamma radiation intensities and heating rates were calculated with the aid of the QAD point kernel computer code (Ref. 5). Sources of radiation used in these calculations are discussed along with the analytical techniques used to describe the test environment. In all cases, the comparable NERVA flight environment is reported in conjunction with the ASTR test levels.

Comparisons are made between the analytical results and measured data in those instances where the tests have already been completed.

This report supersedes, and replaces all data reported in, Reference 1. The earlier report represented an initial attempt to pre-analyze the 901 radiation environment. When the measured spectral data was made available by GD/FW in Reference (6) the improved treatment reported herein became possible. Future reports in the MIT series will discuss improved analytical approaches as they relate to experimentation.

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II OBJECTIVES

II. OBJECTIVES

The major purpose of this report is to document a comparison between NERVA radiation environment and the test environment to which NERVA mechanical components are subjected at the ASTR facility. Both the NERVA and ASTR data are analytical values. However the ASTR analyses are based on a normalization to experimental data in the empty test cell (Reference 6).

Comparisons are also made with measured data for tests which have already been completed. The objective in this analysis as a function of experiment comparison is:

- A. To achieve greater assurance of the accuracy of analytical techniques.
- B. To allow interpolation to any number of dosimeter points in the analytical model to augment the experimental data points.

In general, experimental data is not and will not be available at the most important locations in any given test, for example, the bearings in a bearing tester. It is intended that the data produced by this analysis should serve to fill in this important gap in the test results.

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III DESCRIPTION OF TESTS

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III. DESCRIPTION OF TESTS

The mechanical irradiation tests were conducted at the GD/FW Aerospace Systems Test Reactor (ASTR). A 10 Mw (thermal) reactor capable of producing radiation levels comparable with those to which components will be exposed in a NERVA flight environment. Since the higher power NERVA engine includes an internal radiation shield, the shielded engine component radiation levels may be compared to the lower power but unshielded ASTR values. Figure 1 shows the test cell configuration at ASTR for this series of tests.

The particular components included in each test are described, in the following pages, together with a general discussion of the nuclear and non-nuclear aspects of the test. Greater detail concerning the nuclear aspects of these components is contained in the Radiation Effects Data Book, Reference (7). Further details of the non-nuclear aspects are contained in the relevant test requests, test plans, and specifications contained in Radiation Effects Testing Data Book, Reference (8).

MODIFIED ASTR
(10 MW)

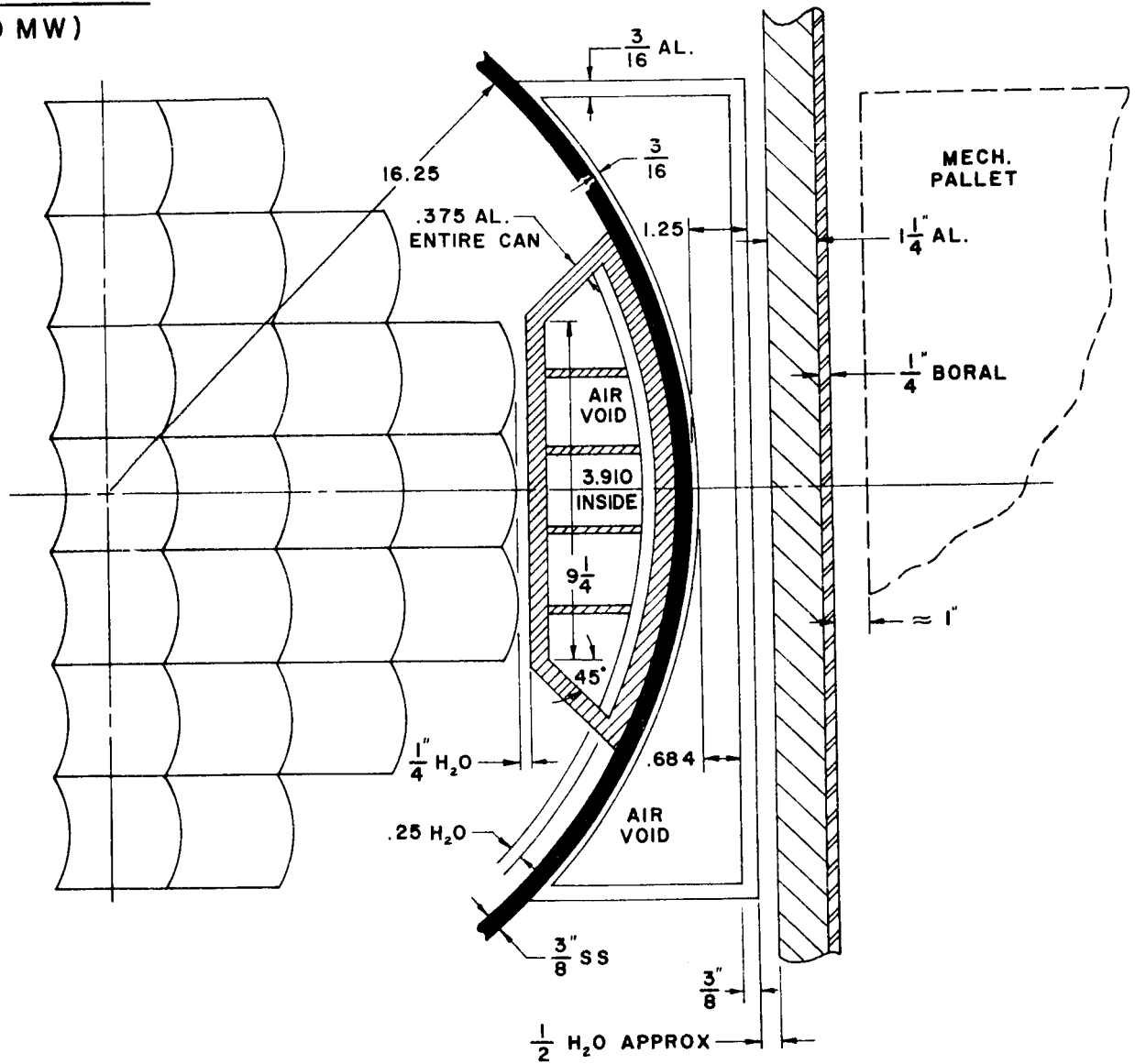


Figure 1

Modified ASTR (10 Mw)

A. MIT-901

Mechanical Irradiation Test 901 includes the following four individual tests. Figure 2 is a photograph of the MIT-901 test pallet with the shroud in place. Figure 3 shows the pallet with the shroud removed.

1. Radiation Effects Test 1/LO01

Radiation Effects Test 1/LO01 involves Configuration 1 of the Tank Shutoff Valve (TSOV).

Figure 4 shows the TSOV in the NERVA context. This valve is a CH_2 -operated poppet valve designed for completely open or completely closed operation to control LH_2 propellant flow from the propellant tank into the propellant feed line.

In this test the TSOV was immersed in LH_2 with the fluid present on both sides of the valve. The liquid flow rate when the valve is open will be relatively small, approximately 0.05 lb/sec. During irradiation the valve was periodically cycled from closed, to open, to closed.

Figure 5 shows the TSOV in the context of Test 901. The position transducer with its mechanical linkage is visible at the left side of the valve, the actuating gas line is on the right, and the LH_2 reservoir is below. The static flange and seal tester with its multiple Marman clamp configuration, and the bearing tester support are in the foreground.

2. Radiation Effects Test 3/LO01

Radiation Effects Test 3/LO01 involves the Turbopump Bearing Assembly, shown in the NERVA context in Figure 4.

This assembly includes the turbopump shaft with its bearing sets and bearing spacers, the housing, and the shaft RPM transducer. An actuating electric motor is provided to drive the shaft from the turbine end at approximately 21,000 rpm. A closure at the pump end is also provided.

No attempt was made to approximate the axial loads of the NERVA application. During the test LH_2 flowed through the assembly at about 0.1 lb/sec.

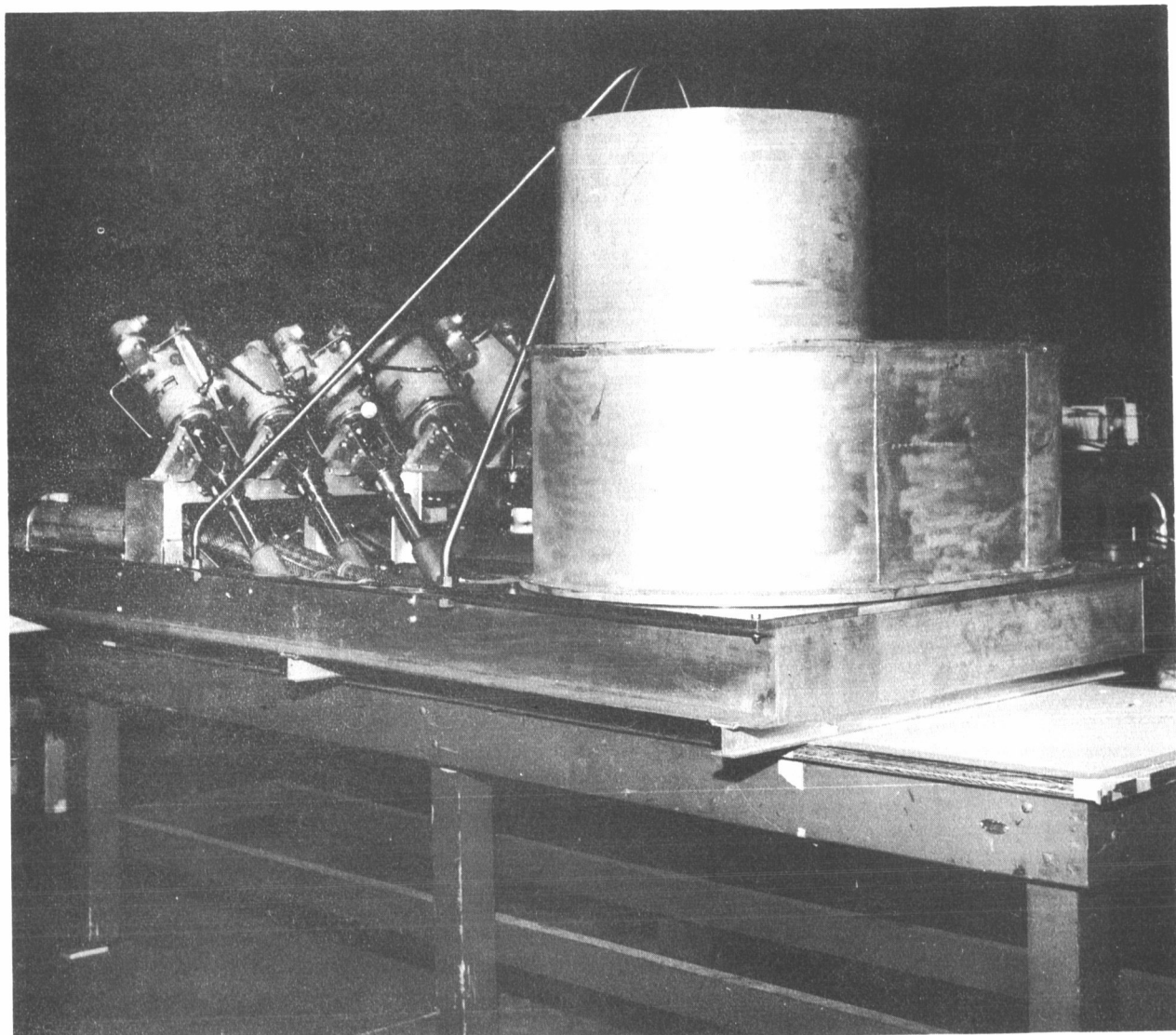


Figure 2

MIT Test Pallet With Shroud in Phase

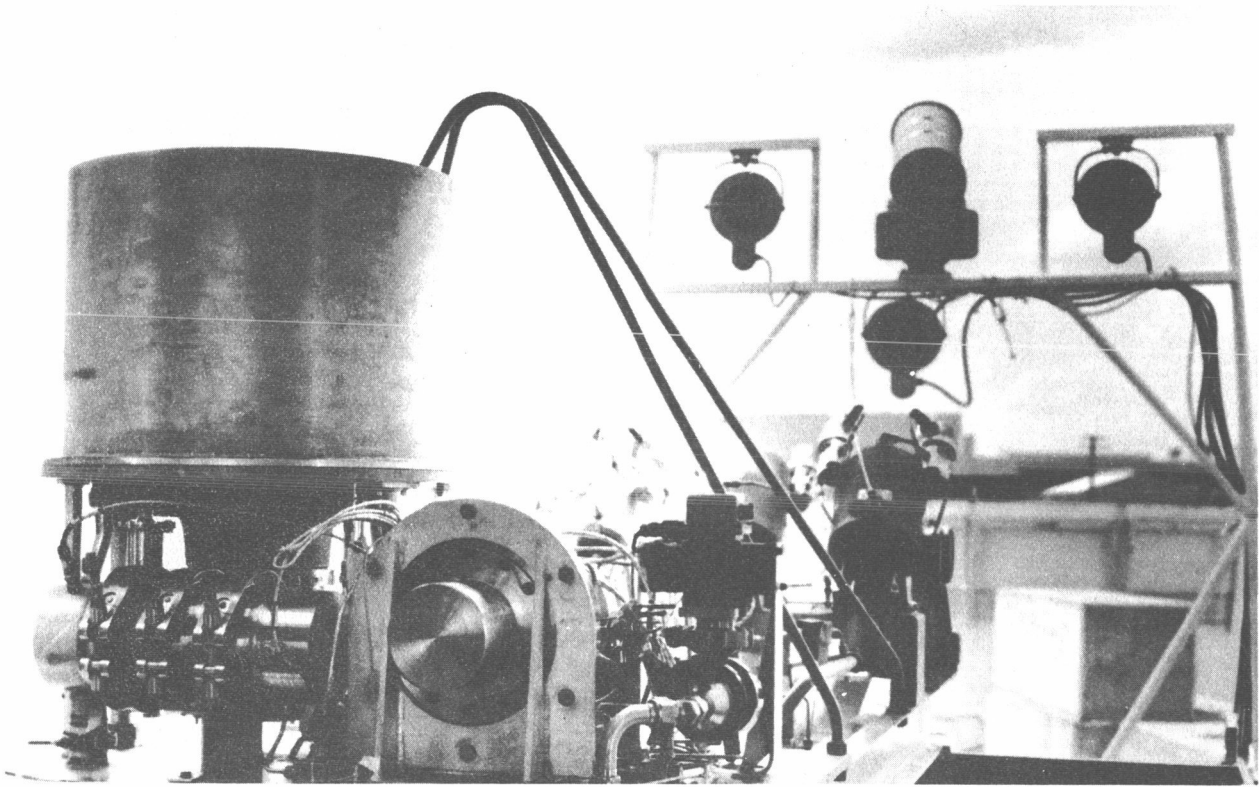


Figure 3

MIT Test Pallet with Shroud Removed

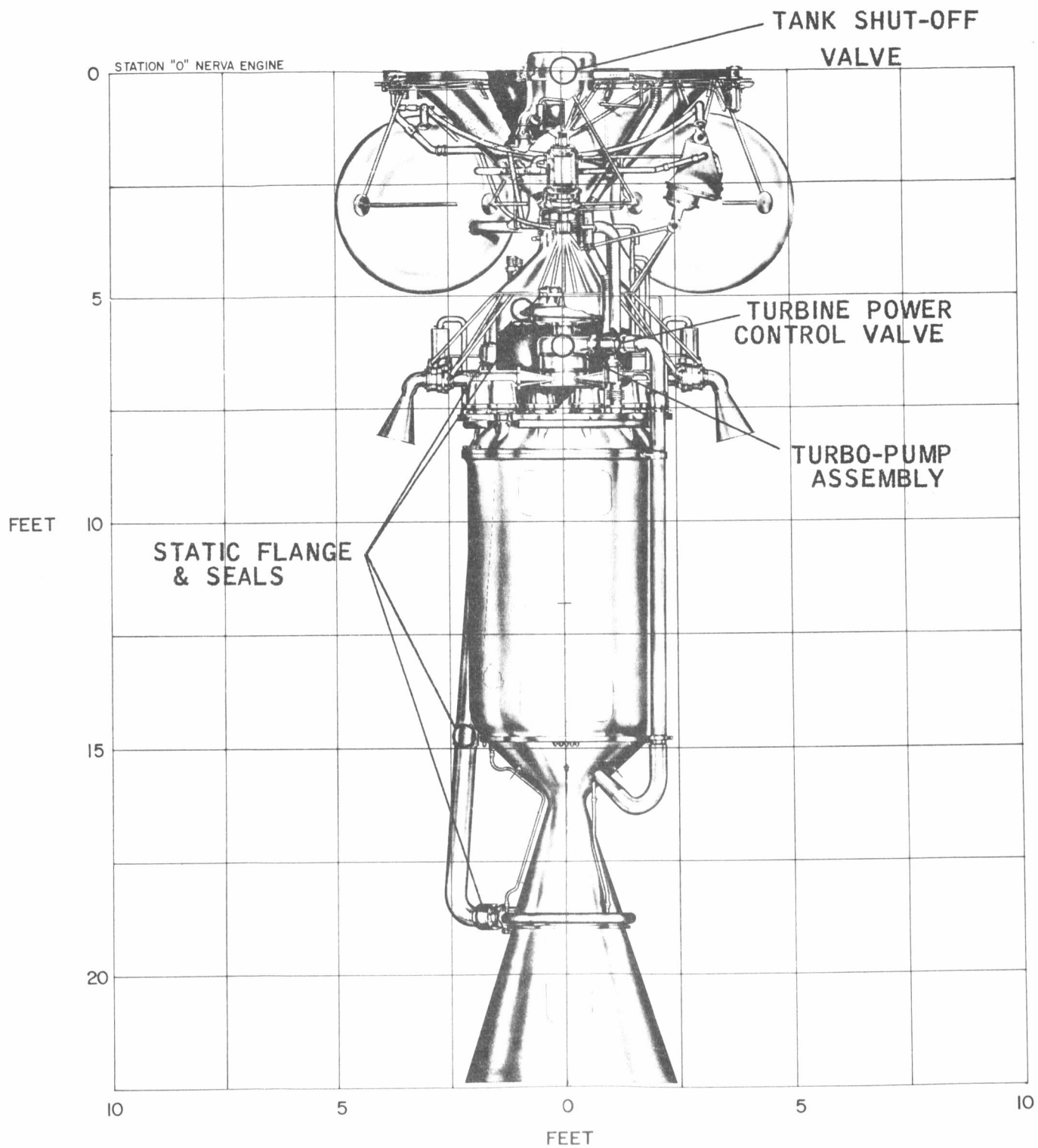


Figure 4

Mechanical Component Locations in NERVA

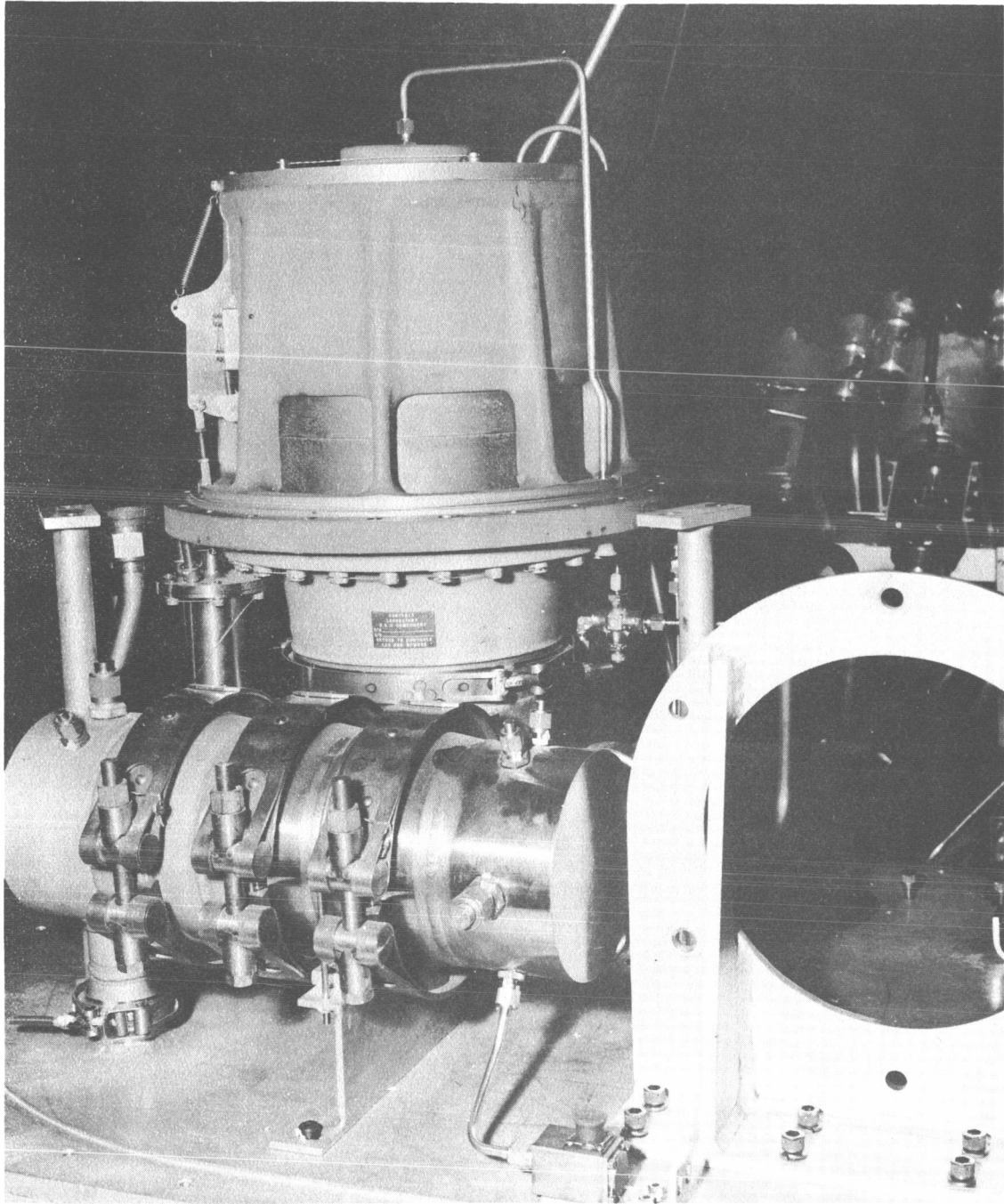


Figure 5

TSOV Location in MIT 901 Test

Figures 6 and 7 show the bearing assembly tester. The section from the middle to the right end is the electric motor drive; the turbine-end bearing-temperature transducer connections are seen in the center of the picture. The connection to the left of center is the rpm transducer connection. The support flange is seen at the left.

3. Radiation Effects Test 8/1001

Radiation Effects Test 8/1001 involves static flanges and metal-to-metal seal combinations. Typical examples of this are shown on the NERVA engine in Figure 4. The test configuration includes three seal combinations; aluminum-to-aluminum, aluminum-to-steel, steel-to-steel. The end covers are secured by Marman clamps to form an enclosure.

Reference is again made to Figure 3. The seal and flange test configuration is mounted on the test pallet with the aluminum seals to the left, and the steel flanges to the right. The LH_2 pressure transducer is located in the lower center foreground.

4. Radiation Effects Test 4/1001

Radiation Effects Test 4/1001 involves the Turbine Power Control Valve (TPCV) which is located on the NERVA engine in Figure 4. The TPCV is a butterfly-type valve designed to regulate the flow of high temperature GH_2 to the turbopump turbine, thus controlling the turbine power. The loss of the valve or knowledge of its position during NERVA operation would be most serious for engine operation, making imperative the design of a reliable valve.

The test configuration includes a pneumatic linear actuator which will position the valve blade during the test to regulate the flow of ambient temperature GH_2 . The test actuator is not intended for NERVA application. The operational actuator is being developed under a different program, and will be mated to the TPCV in a later radiation effects test.

Figure 3 also shows the TPCV with its actuator, and other test components, mounted in their relative positions on the test pallet. The light colored box on top of the actuator is the position sensing transducer. The valves

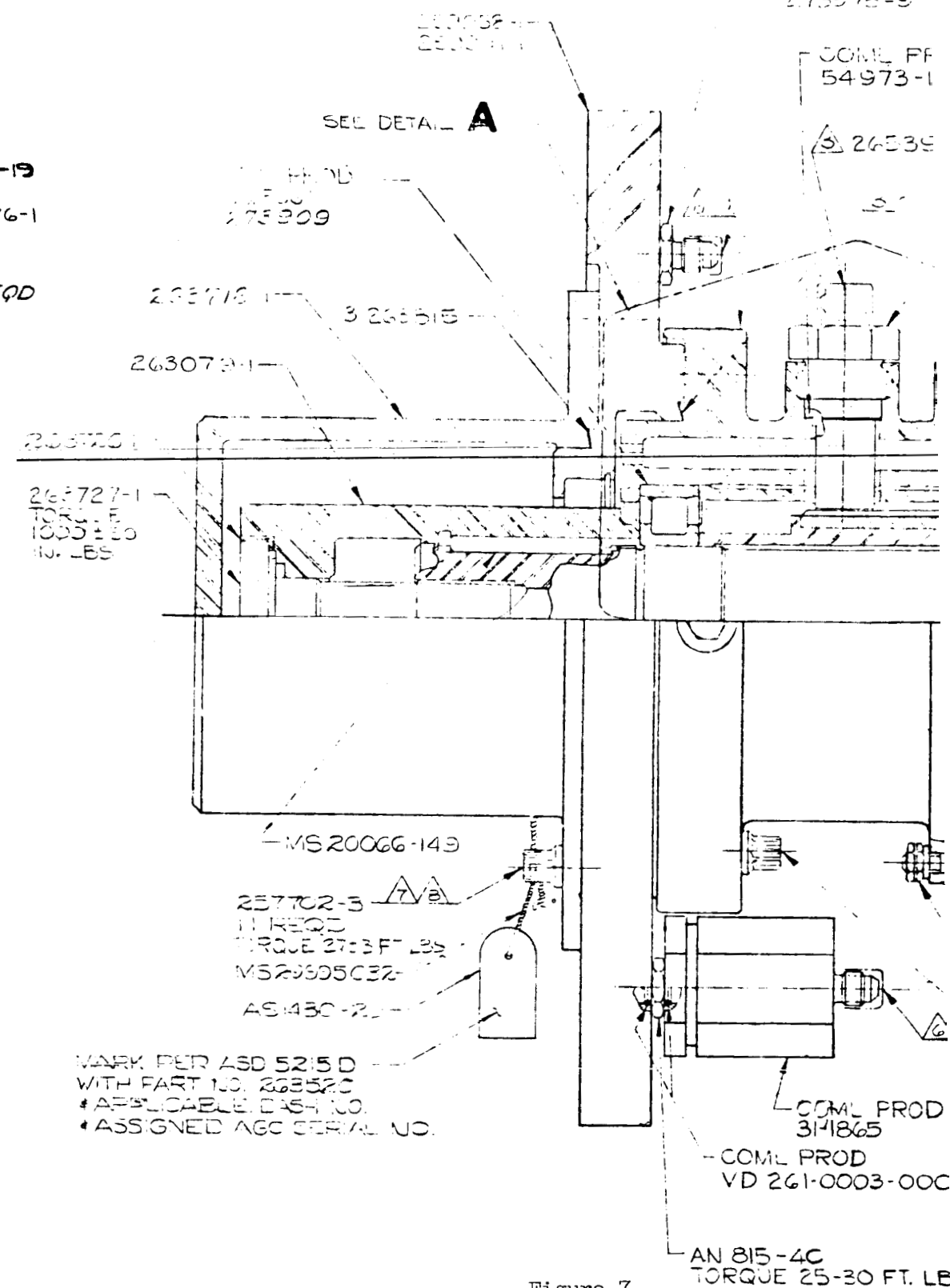
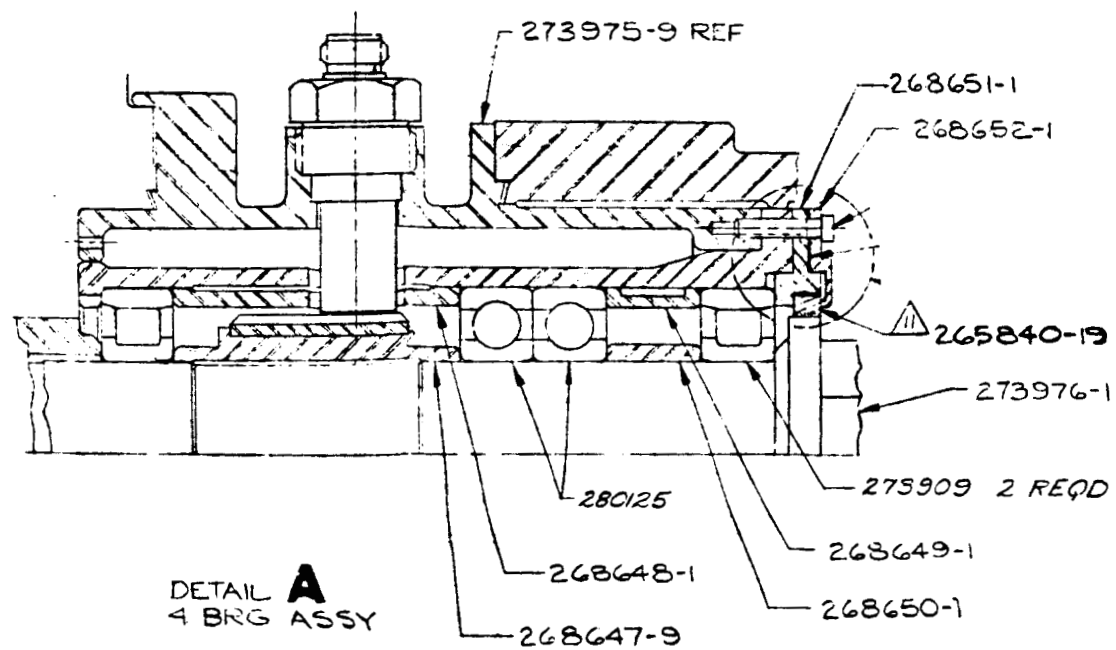


Figure 7

MIT 901 Bearing Tester Assembly

$$\frac{1}{2} \text{CD}$$

259954-1
25990-1
268610-3

1755-1

572-2

→ 5

257123-5 REQD TORQUE 9±1 IN. LBS
257123-5 TORQUE TORQUE 55±5 IN. LBS
257123-5 TORQUE TORQUE 55±5 IN. LBS

-2693804
259972-1

256209-1
2 REV

-259953-1-50K-5

AN 3/4 C-4
TORQUE 300
= 25 IN. LBS

COML PROD
FIC-428-1
12 RECD
TORQUE 115 ± 5 IN. LBS

3 COML PROD
7331-1

COML PROC
NO. 5660
280125

257702-5 Δ 7 8 NO.
8 REQD. 280
MS 20995 C32
TORQUE 27 \pm 3 FT. LBS.

257183-3 12 REQD
257183-7 10 REQD
M620995C32
TORQUE 115±5
IN. LBS.

FOLDOUT FRAME

63

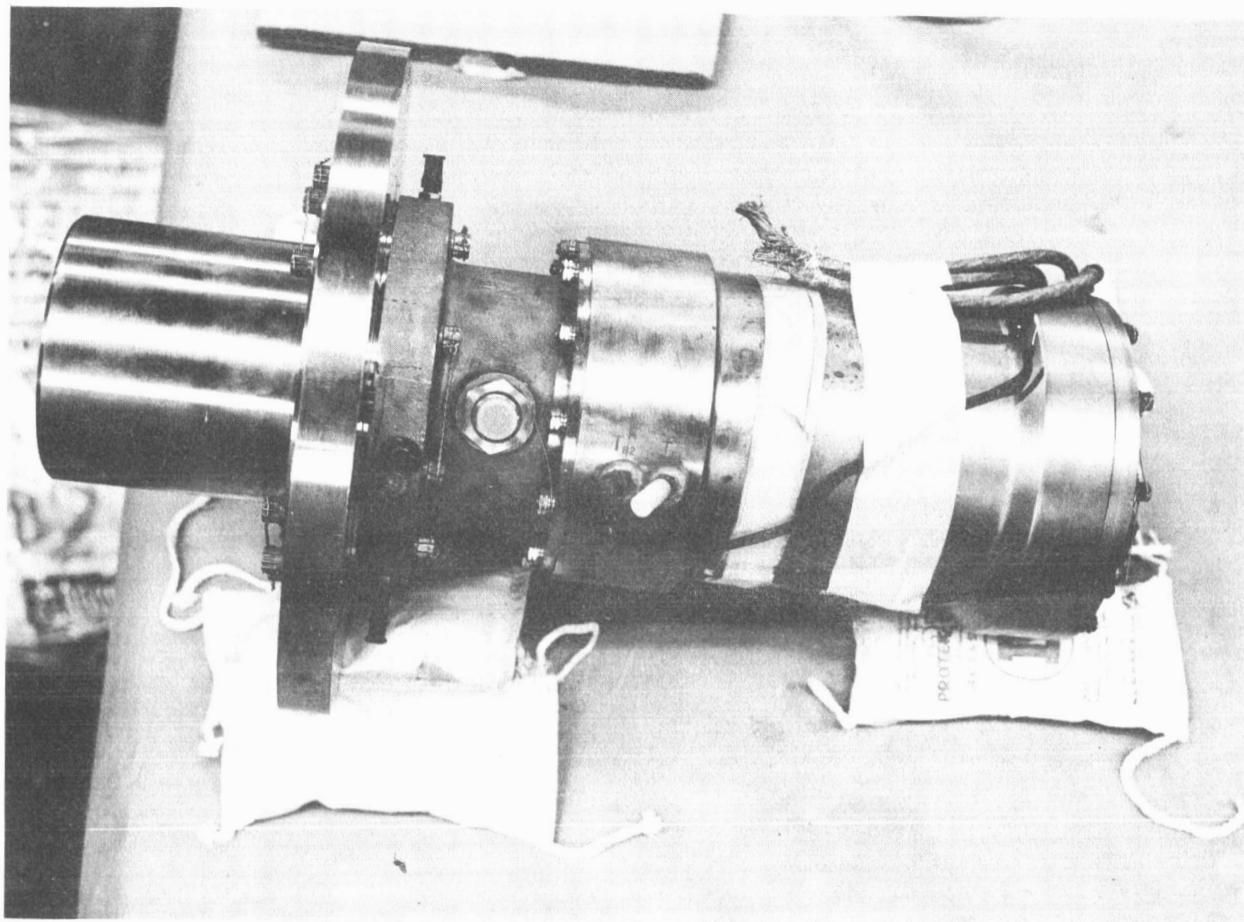


Figure 6

MIT 901 Bearing Tester (Photograph)

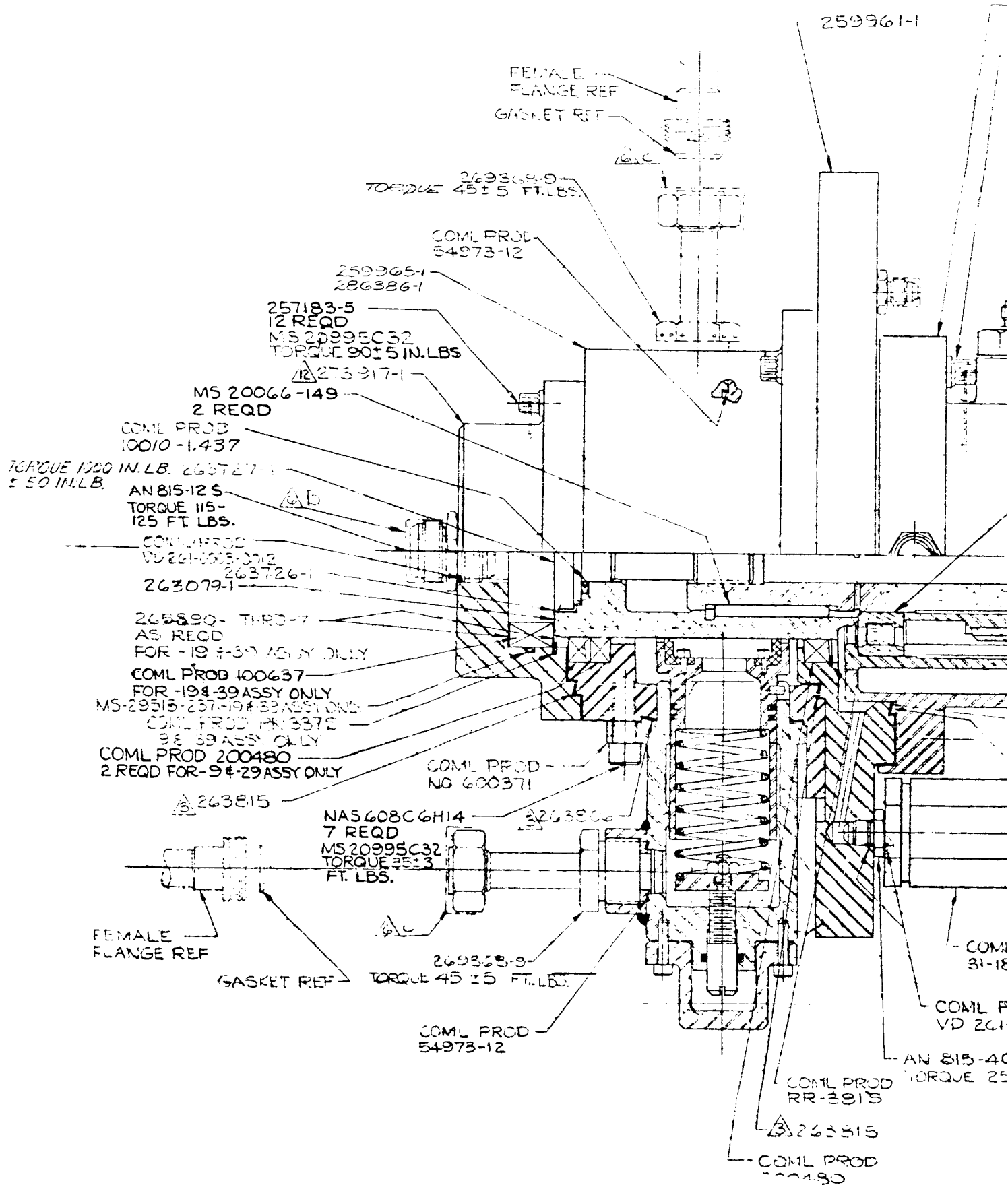
which regulate the environmental gases and liquids can be seen in the background, as can some of the necessary piping. The TSOV is enclosed in a cryostat to contain the LH_2 bath. The remainder of the components are enclosed by a cover (as shown by Figure 1), which contains an inert atmosphere of helium to prevent an explosion of leaking GH_2 . Test duration, at full reactor power of 10 megawatts, was 327 seconds.

B. MIT-902

The test hardware for the MIT-902 test consisted of a modified MIT-901 bearing tester enclosed by itself on the MIT-901 pallet. The MIT-901 bearing tester was modified to permit radial and axial loading of the turbopump shaft. The modifications added an appreciable amount of stainless steel in the end of the tester towards the reactor. This has the effect of causing a reduction (from the results of the MIT-901 test) in gamma dose and heating rates and in the neutron flux levels at the bearings located behind the added material. Figure 8 is an engineering drawing showing the modifications and the Armalon layed bearing configuration tested. Test duration at reactor full power was 300 sec.

C. MIT-903

MIT-903 test used the MIT-902 bearing tester and pallet unmodified. Armalon caged bearings were again tested, however the test duration was increased to 600 sec. Figure 8 is again referenced to show the bearing tester and bearing configuration. The increased test duration resulted in integrated levels of gamma ray dose and neutron flux of twice that experienced by the MIT-902 test.



FOLDDOUT FRAME /

269379-69

757 12.5 TOP 35-35 FT. LBS
 2 REQD - MS 20995 C 32
 13005320

265381-1
 TORQUE 45.5 FT. LBS

COML PROD
 54973-12

COML PROD
 2 REQD
 TORQUE 130.5
 111. LBS.

COML PRODS
 NO. 7331-5
 NO. 7331-1
 NO. 7331-3

257183-6
 12 REQD
 MS 20995

259953-2
 2 REQD
 AN 316
 TORQUE

257183-11 12 REQD
 TORQUE 55.5 IN. LBS
 MS 20995 C 32

278029-1 FOR-5
 A5 REQD

254064-1

265871-1
 265872-9
 263818

284926-1

PROD
 165
 ROD
 0003-0004

30 FT. LBS.

263270-69

Figure 8

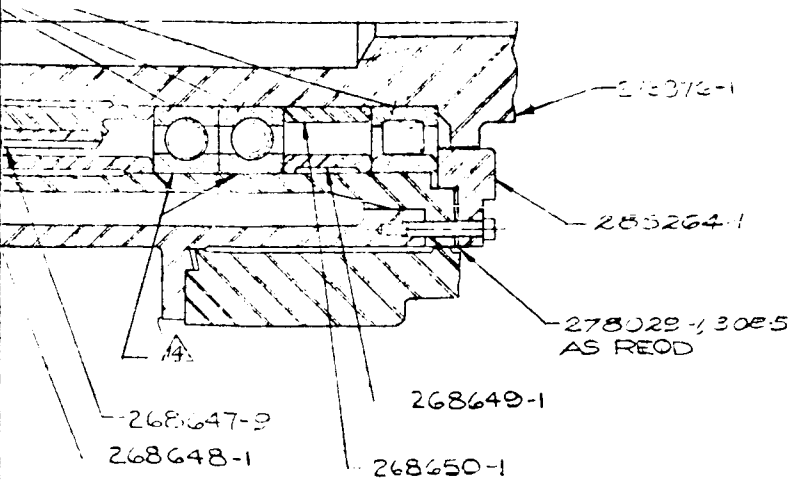
Refined Bearing Tester Assembly

FOLDOUT FRAME 2

TORQUE 9015 IN LBS.

-122

CHIL R
500 ±25 IN LBS



-29 4-39 ASSY

D. MIT-904

MIT-904 test hardware is, at present, unmodified from the MIT-902 and 903 configuration. The same pallet and bearing tester are to be used. However, a four, Armalon caged bearing configuration will be tested instead of the three bearing group tested in MIT-902 and 903. Figure 8 shows in the upper right hand corner the bearing configuration planned for the test. Test duration is planned to be 3600 sec, see Reference 9.

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IV RADIATION ANALYSIS

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IV. RADIATION ANALYSIS

Basically, the techniques adopted for obtaining predicted radiation levels and heating rates were semi-empirical in nature. That is to say, the radiation sources were adjusted in their magnitude so that the calculated dose-rates at a given reference location were made to agree with measured data. This normalization to measurement was made at a distance of 12 inches from the test cell wall opposite the center of the core, for the case where the test cell was empty.

Having obtained sources for the calculable model which were designed to give the same result as a measurement in the unperturbed test cell, the analysis was performed by first mapping the remaining volume of the empty test cell and proceeding with alternate mockups of the test equipment. A recognized shortcoming of this technique is that all the sources are "lumped" into the active core. There are two areas of weakness in doing this. First, data calculated at points much closer to the core than the point of normalization are lower than measured values, since the capture gamma ray sources in the reactor structure (such as pressure vessel) have been juxtapositioned further from the detector location. This has been shown to represent no particular problem in conjunction with the tests under discussion, however, because points of interest are close to the point of normalization. The second weakness in this approach is that the effects of scattering from the test cell walls, and the existence of capture gamma ray sources in the walls, are not included. However, such contributions are difficult to analyze and quite often are not included in irradiation test evaluations. These contributions are made less important in the tests in question since the test equipment shields out some of these contributions as they affect such areas as the bearings. The scattered gamma radiation is particularly sensitive to this shielding effect since scattered gamma rays are so low in energy compared to direct radiation. To leave out these indirect contributions has the effect of slightly underestimating the test environment in selected cases. This is much less of a problem than overestimating the test environment in relating it to the NERVA flight condition.

TABLE 1GAMMA RAY SOURCE
STRENGTH AND SPECTRUM

Group	Energy Interval (mev)	Effective Energy (mev)	Source Strength (mev/sec)
1	0 - 1.0	0.5	2.66×10^{18}
2	1.0 - 2.0	1.5	1.59×10^{18}
3	2.0 - 3.0	2.5	1.16×10^{18}
4	3.0 - 5.0	4.0	5.02×10^{17}
5	5.0 - 8.0	7.0	5.99×10^{17}
TOTAL			6.51×10^{18}

A. GAMMA RADIATION ANALYSIS

The gamma ray analysis was based on a normalization of the calculated dose rate to the measured unperturbed value at 12 inches from the test cell wall. The measured data was obtained from Table 3.2 of Reference (6). The calculated gamma ray spectrum was made to agree with the spectrum measured at a distance of 25 feet from the center of the core (as reported in Figure 3.4 and Table 3.9 of Reference (6)). Figure 3.4 is reproduced here as Figure 9 for reference purposes. The result of this source normalization is indicated by the source strength spectrum presented in Table 1.

The QAD computer code (Reference 5) was used for gamma radiation calculations. Figure 10 shows how the calculated unperturbed dose rates compare to the measured data of Reference (6). It will be noted in this Figure that the calculated values agree with the measured data from perfect agreement at the point of normalization to a condition where the calculated value is a factor of 2.65 below the measured value at a distance of 72 inches from the test cell wall. The reason for the divergence of the two curves is the inclusion of scattered and capture gamma ray contributions in the test cell walls in the measured results. However, as pointed out earlier, the self-shielding of the test specimens has the effect of markedly reducing the contribution of scattered gamma radiation. Scattered radiation is believed to be responsible for a very large portion of the discrepancy noted in the unperturbed traverse of Figure 10.

Unperturbed gamma dose rates were calculated at all points where perturbed test condition radiation intensities were desired. Each mechanical irradiation test configuration was then mocked up as a QAD computer model, and the test environment gamma dose rates and gamma heating rates were determined.

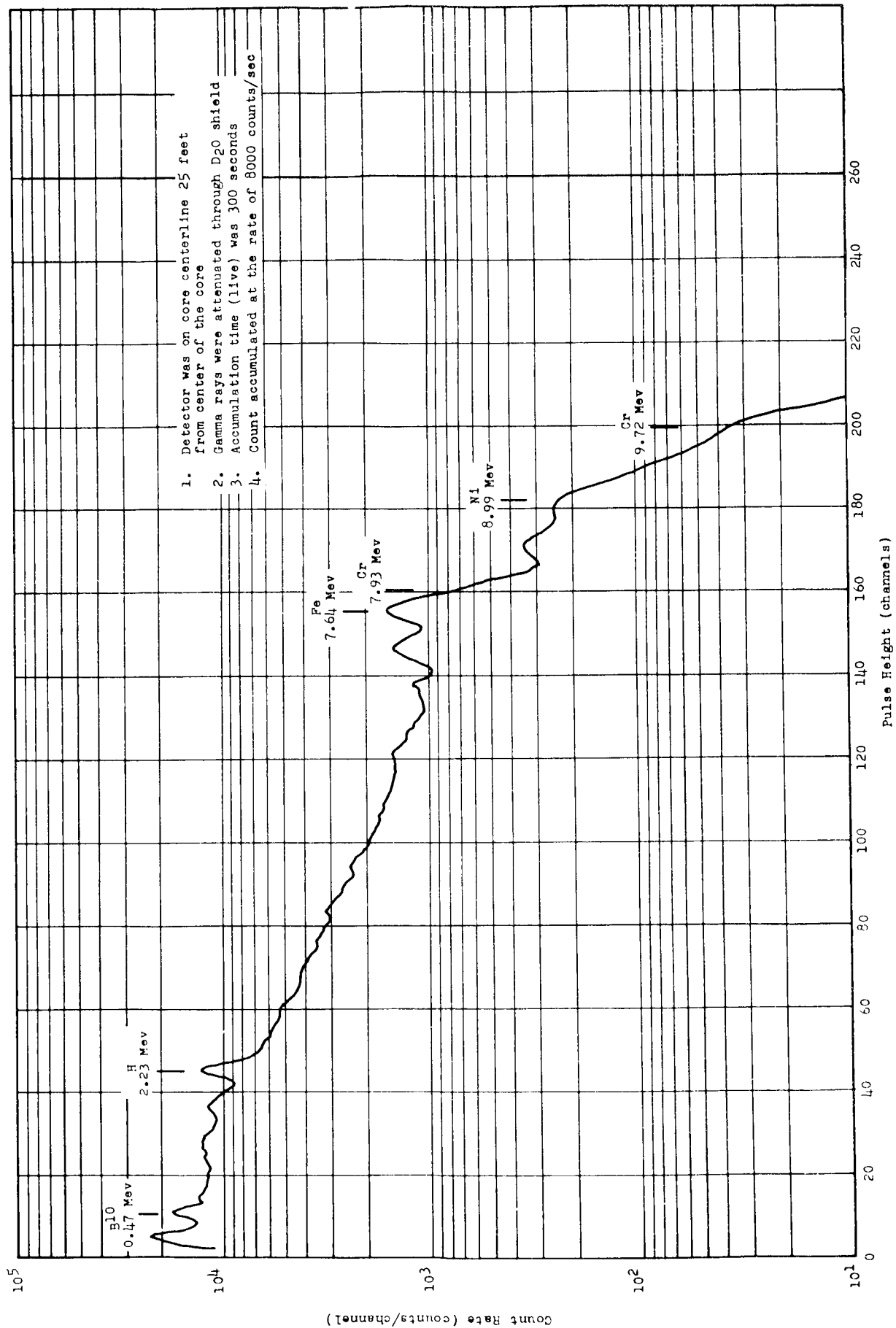


Figure 9

Pulse Height Spectrum of Gamma Rays from the 10 Mw ASTR

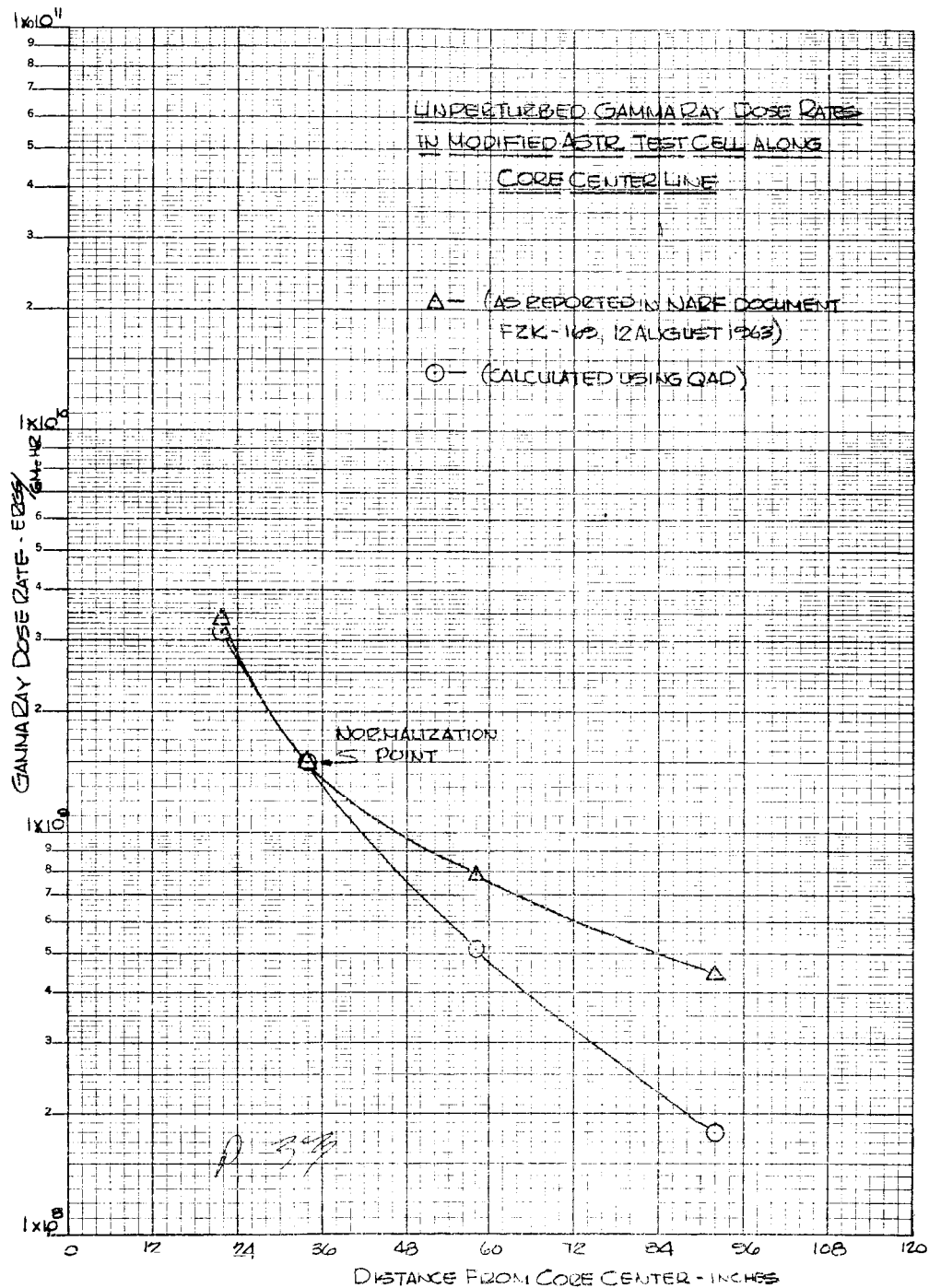


Figure 10

Unperturbed Gamma Ray Dose Rates in ASTR Test Cell

B. NEUTRON ANALYSIS

A similar approach was used in obtaining calculated neutron levels. First a normalization of source strength was completed such that the QAD calculated value (using effective removal theory) was made to agree with the measured neutron flux at a distance of 12 inches from the test cell wall. The neutron spectrum was based on the analytical spectrum reported in Figure 3.3 of Reference (6) and reported here as Figure 11.

An unperturbed neutron flux traverse was calculated along the test cell centerline, in the same manner as described in the gamma radiation analysis. Figure 12 shows this calculated traverse as it compares to the measured data of Reference (6). The fast neutron flux is based on a normalization to the measured flux above 0.85 Mw as reported in Table 3.2 of Reference (6). The fast neutron flux was then increased by a factor of 2.12 to include that portion of the spectrum shown in Figure 11 in the energy range from 0.01 Mw to 0.85 Mev. Final fast neutron flux values therefore are quoted above 0.01 Mev. These data then are directly comparable to NERVA data which is based on the same energy cut off point.

These calculations were based on a single energy group effective removal concept. The fast neutron source within the reactor was normalized to the measured 0.85 Mev threshold detector data and multiplied by a factor of 2.12 to include neutrons down to 0.01 Mev. The resultant source strength was 8.40×10^{17} n/sec for the 10 mw power level condition.

Unperturbed and perturbed (that is, test components in place) neutron fluxes above 0.01 Mev were calculated, using the QAD computer code, for all points of interest in the mechanical irradiation tests.

Figures 13, 14, and 15 show the analytical models used to describe the TSOV, TPCV, and bearing test for the QAD calculations.

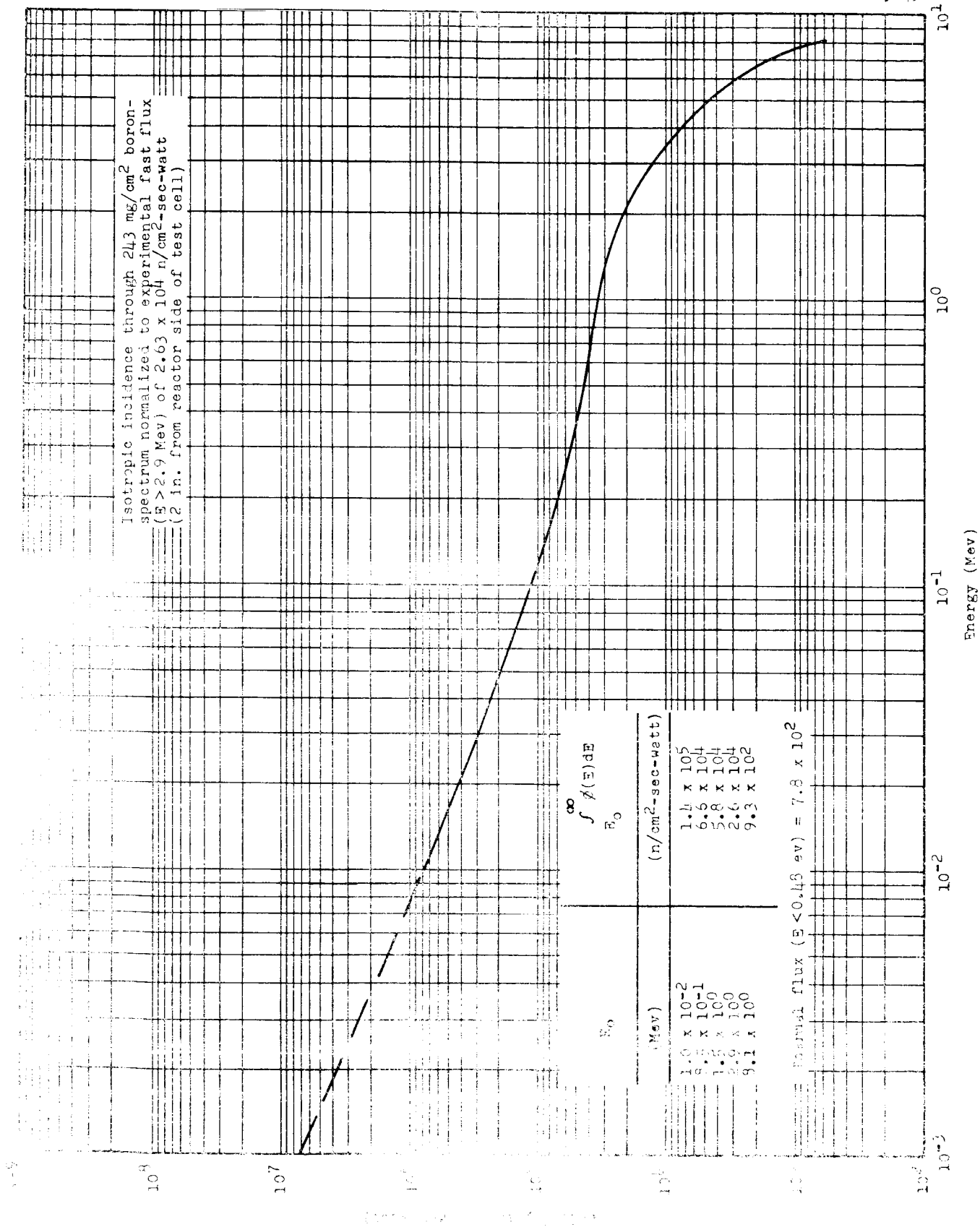


Figure 11

Analysis of the Data for the Spectrum

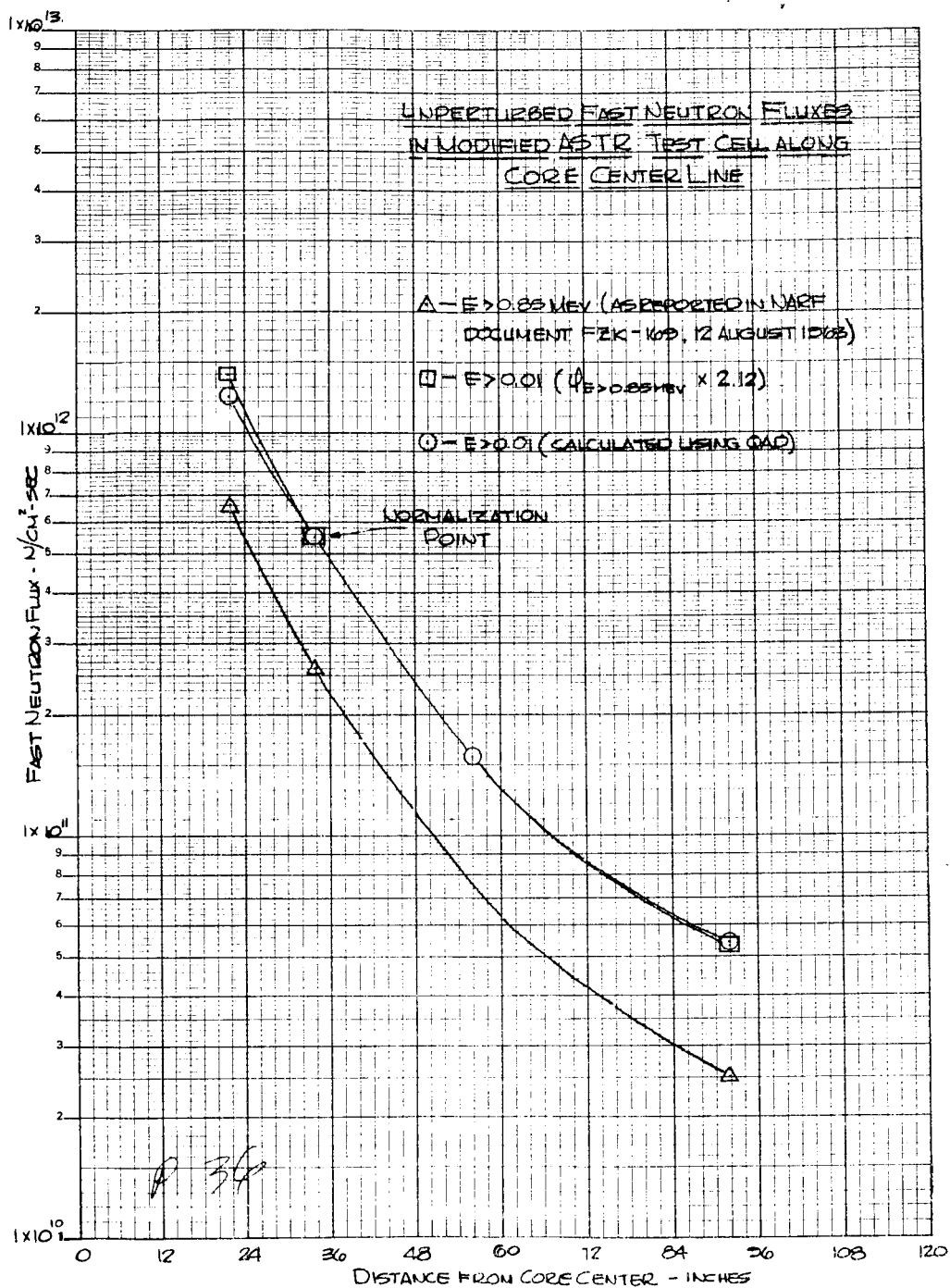
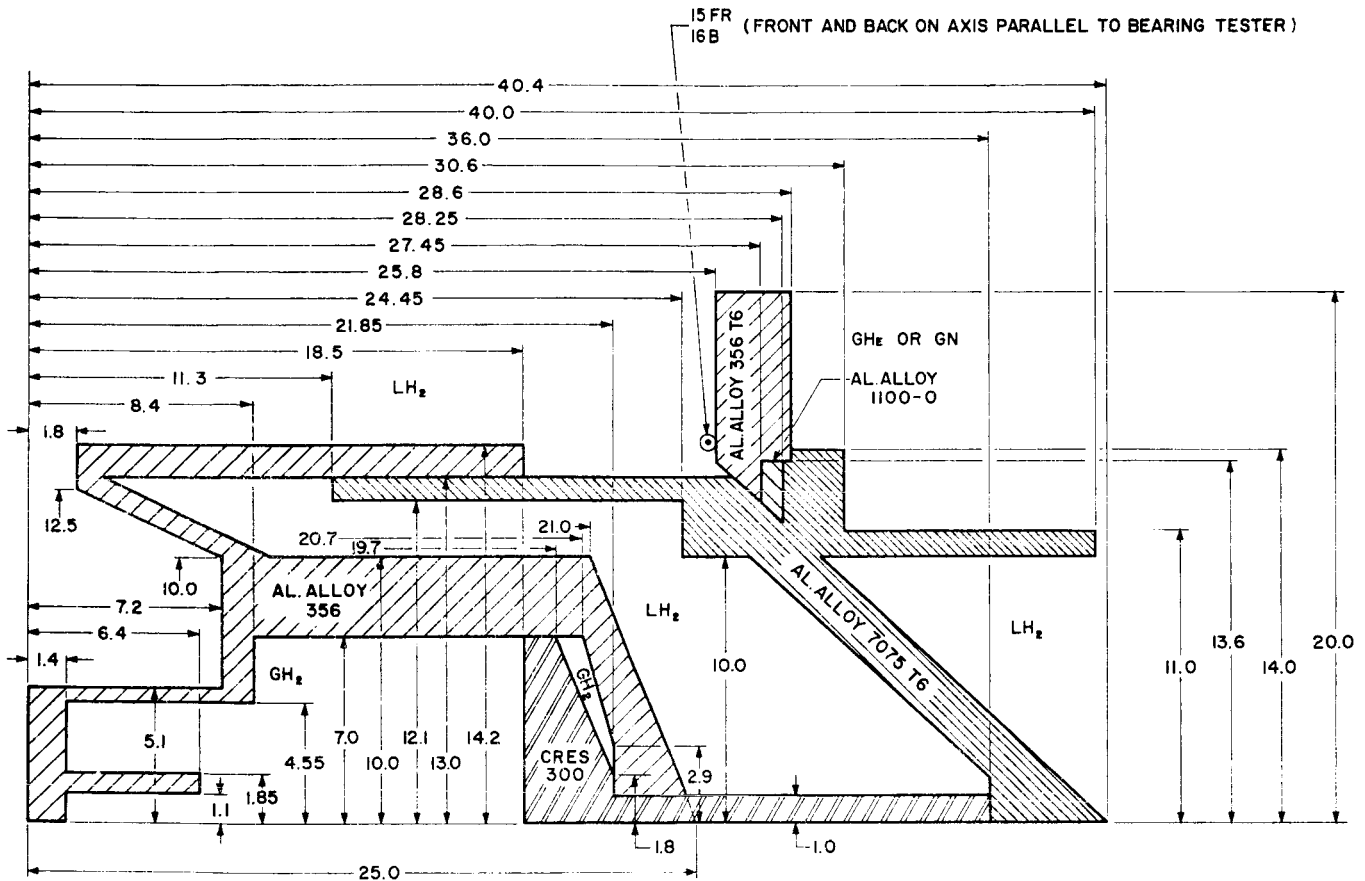


Figure 12

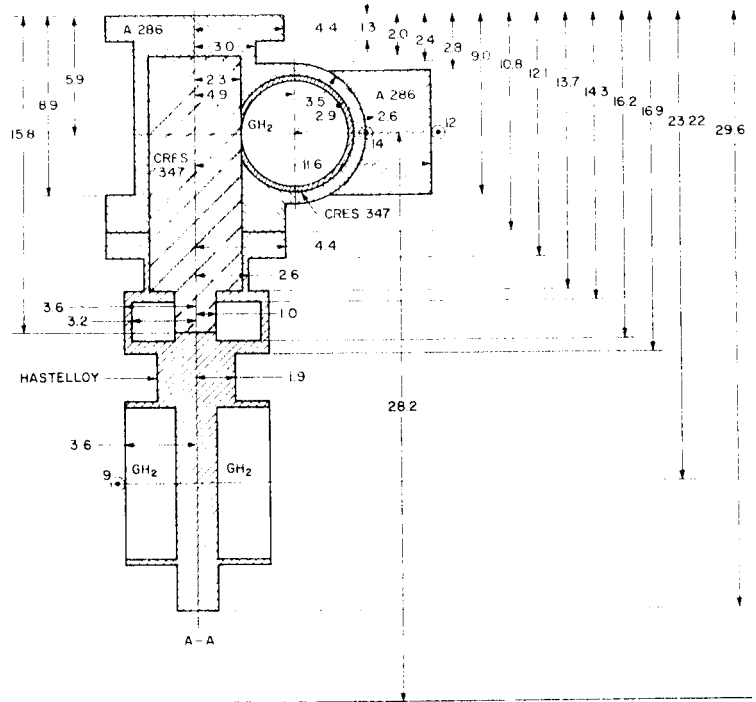
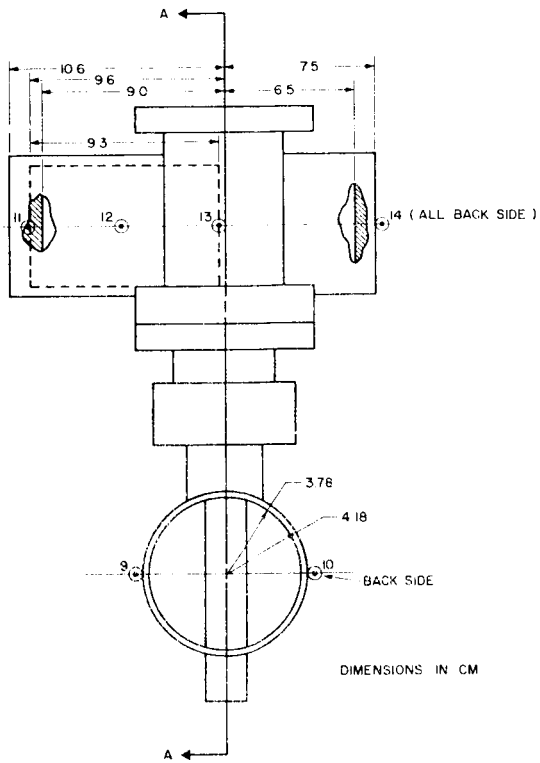
Unperturbed Fast Neutron Fluxes in ASTR Test Cell



DIMENSION ARE IN CM.

Figure 13

Analytical Model - TSOV



TPCV
PART NUMBER 260563

Figure 14
Analytical Model - TPCV

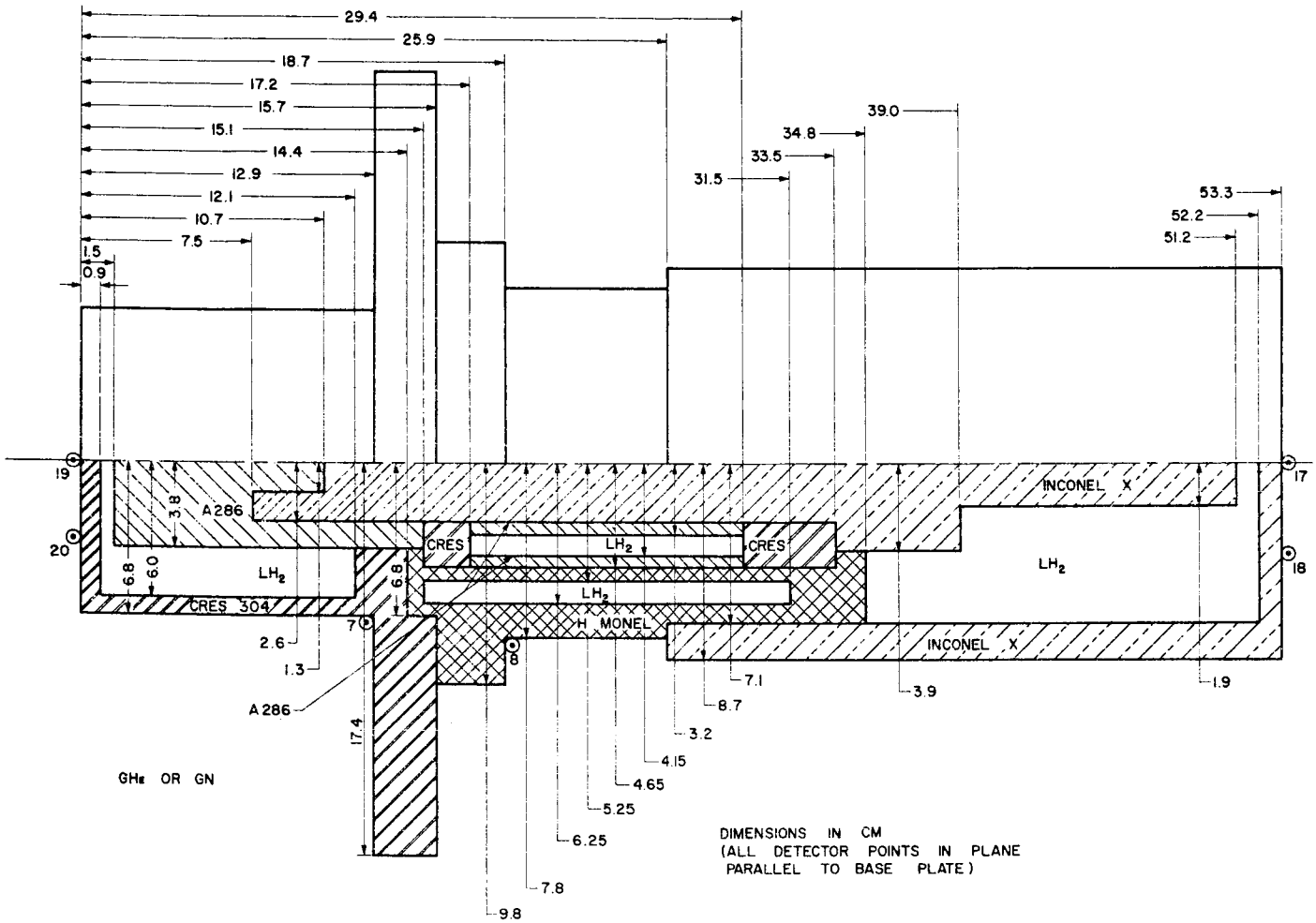


Figure 15
Analytical Model Bearing Tester

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V CALCULATED RADIATION ENVIRONMENT

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V. CALCULATED RADIATION ENVIRONMENT

The results of the QAD computer program calculations are presented in this section. Neutron and gamma radiation intensities are described along with gamma heating rates. In addition, the neutron-to-gamma number flux ratio is also reported for a number of dose-point locations in the various MIT tests. Finally, comparisons are made with comparable NERVA flight environment conditions as they are known at the time of this writing.

A. MIT-901

Table 2 presents the results of the analysis of the MIT-901 radiation environment. Gamma dose rates are reported in units of (ergs/gm) of carbon per hour at the ASTR 10 Mw power level. Integrated gamma doses are given in terms of (ergs/gm) of carbon for a total exposure time of 327 seconds. Gamma ray number fluxes are given in units of ($\gamma/\text{cm}^2\text{sec}$). Fast neutron fluxes for $E > 0.01$ Mev are reported in the following manner: two values are given: an unperturbed flux with no test configuration in place, and a perturbed flux as calculated with effective removal theory. Removal theory is known to over-estimate the neutron attenuation of metals in a condition such as the present one. Therefore, the most probable flux level is somewhere in the range given for each component. The unperturbed flux will hereafter be referred to as the maximum value in each case. Two n/ γ flux ratios are given in correspondence with the two neutron flux values. The heating rates are in terms of (BTU/sec) per cubic inch of the material in which the detector is located. Table 3 provides a comparison between the data for the ASTR test and the current predictions of the NERVA flight conditions. This comparison is limited to the TSOV, TPCV, and turbopump bearings because they represent the only components which have spatically defined locations in NERVA.

Figure 16 depicts the location of the dose points in the MIT-901 analysis.

This test has been completed. Comparisons with some test results are given in a later section.

RADIATION ENVIRONMENT AND HEATING RATES FOR MECHANICAL
TEST - 901 (327 sec Duration)

Detector Point	Detector Location	Material at Detector Location	Gamma Ray Dose-Rate (ergs/gm(c)hr)	Int. Gamma Ray Dose (ergs/gm(c))	Gamma Ray No. Flux ($\gamma/cm^2/sec$)	Fast Neutron Flux $E > 0.01$ Mev (n/cm ² -sec)	Neutron/Gamma No. Flux Ratio	Gamma Heating Rate (BTU/in ² -sec)
1	Flange and seal test - Al to Al flange	Al 6061	7.8×10^8	7.1×10^7	3.8×10^{12}	$1.1 - 1.7 \times 10^{11}$	0.029 - 0.044	8.9×10^{-4}
2	Flange and seal test - Al to SS flange	Al 6061	1.2×10^9	1.1×10^8	5.8×10^{12}	$2.4 - 3.5 \times 10^{11}$	0.041 - 0.060	1.3×10^{-3}
3	Flange and seal test - SS to SS test	SS 347	1.8×10^9	1.6×10^8	8.7×10^{12}	$4.7 - 5.2 \times 10^{11}$	0.054 - 0.060	6.2×10^{-3}
4	Bearing test	SS 302	6.4×10^8	5.8×10^7	3.1×10^{12}	$2.4 - 6.0 \times 10^{11}$	0.077 - 0.19	2.2×10^{-3}
5	Bearing test	Inconel X	4.7×10^7	4.3×10^6	2.3×10^{11}	$0.6 - 5.7 \times 10^{11}$	0.26 - 2.5	2.0×10^{-4}
6	Bearing test	SS 302	3.5×10^8	3.2×10^7	1.7×10^{12}	$1.7 - 5.5 \times 10^{11}$	0.10 - 0.32	1.3×10^{-3}
7	Bearing test - Pump end bearing	SS 302	1.8×10^8	1.6×10^7	8.7×10^{11}	$1.0 - 5.6 \times 10^{11}$	0.11 - 0.64	7.5×10^{-4}
8	Bearing test	Inconel X	3.1×10^7	2.8×10^6	1.5×10^{11}	$0.4 - 5.2 \times 10^{11}$	0.27 - 3.5	1.2×10^{-4}
9	Bearing test	H Monel	1.8×10^8	1.6×10^7	8.7×10^{11}	$1.3 - 5.0 \times 10^{11}$	0.15 - 0.57	6.5×10^{-4}
10	Bearing test	Inconel X	8.5×10^6	7.7×10^5	4.1×10^{10}	$0.2 - 4.2 \times 10^{11}$	0.49 - 10	3.4×10^{-5}
11	Bearing test	A 286	6.8×10^7	6.2×10^6	3.3×10^{11}	$0.4 - 4.2 \times 10^{11}$	0.12 - 1.3	2.8×10^{-4}
12	Bearing test	Inconel X	7.7×10^7	7.0×10^6	3.7×10^{11}	$0.6 - 4.2 \times 10^{11}$	0.16 - 1.1	2.8×10^{-4}
13	Bearing test - Turbine end bearing	SS 302	2.3×10^7	2.1×10^6	1.1×10^{11}	$0.2 - 3.9 \times 10^{11}$	0.18 - 3.5	9.8×10^{-5}
14	Bearing test - Turbine end bearing	SS 302	2.3×10^7	2.1×10^6	1.1×10^{11}	$0.2 - 3.7 \times 10^{11}$	0.18 - 3.4	9.9×10^{-5}
15	Bearing test	Inconel X	3.5×10^6	3.2×10^5	1.7×10^{10}	$0.08 - 3.5 \times 10^{11}$	0.47 - 22	1.4×10^{-5}
16	Bearing test - Turbine end bearing	SS 302	8.1×10^6	7.4×10^5	3.9×10^{10}	$0.1 - 3.6 \times 10^{11}$	0.26 - 9.2	3.6×10^{-5}
17	Bearing test	H Monel	1.4×10^7	1.3×10^6	6.8×10^{10}	$0.2 - 3.5 \times 10^{11}$	0.29 - 5.1	5.5×10^{-5}
18	Bearing test	Inconel X	8.4×10^5	7.6×10^4	4.1×10^9	$0.02 - 2.3 \times 10^{11}$	0.49 - 56	3.4×10^{-6}
19	Bearing test	Inconel X	5.2×10^6	4.7×10^5	2.5×10^{10}	$0.06 - 2.4 \times 10^{11}$	0.24 - 9.6	2.0×10^{-5}
20	TPCV	Hastelloy B	1.1×10^9	1.0×10^8	5.3×10^{12}	$3.0 - 3.5 \times 10^{11}$	0.057 - 0.066	4.2×10^{-3}
21	TSOV	A 356	4.9×10^8	4.4×10^7	2.4×10^{12}	$1.2 - 2.2 \times 10^{11}$	0.050 - 0.092	5.6×10^{-4}

Table 2
Radiation Environment - MIT 901

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TABLE 3
COMPARISON OF
NERVA AND 901 TEST ENVIRONMENTS

A. NERVA - (1100 SEC)							
Component	Maximum γ - Dose Rate (erg/gm-hr)	Maximum γ - Dose (erg/gm)	Maximum γ - Flux (γ /cm ² -sec)	Maximum n-Flux E > 0.01 Mev (n/cm ² -sec)	Maximum nvt (n/cm ²)	Maximum n/ γ Flux Ratio	Maximum Gamma Heating Rate (BTU/in ² -sec)
TSOV	6.0×10^7	2.0×10^7	1.8×10^{11}	3.0×10^{10}	3.6×10^{13}	0.17	2.0×10^{-5}
TPCV	1.4×10^9	4.7×10^8	4.6×10^{12}	4.0×10^{11}	4.8×10^{14}	0.09	5.3×10^{-3}
BEARINGS, PUMP END	1.1×10^7	3.7×10^6	3.4×10^{10}	1.0×10^{11}	1.2×10^{14}	2.9	5.9×10^{-5}
BEARINGS, TURBINE END	1.4×10^8	4.7×10^7	4.3×10^{11}	1.0×10^{11}	1.2×10^{14}	0.23	7.5×10^{-4}
B. ASTR - 307 SECOND RUN							
Component	Maximum γ - Dose Rate (erg/gm-hr)	Maximum γ - Dose (erg/gm)	Maximum γ - Flux (γ /cm ² -sec)	Maximum n-Flux E > 0.01 Mev (n/cm ² -sec)	Maximum nvt (n/cm ²)	Maximum n/ γ Flux Ratio	Maximum Gamma Heating Rate (BTU/in ² -sec)
TSOV	4.9×10^8	4.4×10^7	2.4×10^{12}	2.2×10^{11}	7.2×10^{13}	0.092	5.6×10^{-4}
TPCV	1.1×10^9	1.0×10^8	5.3×10^{12}	5.5×10^{11}	1.1×10^{14}	0.096	4.2×10^{-3}
BEARINGS, PUMP END	1.8×10^8	1.6×10^7	8.7×10^{11}	5.0×10^{11}	1.8×10^{14}	0.64	7.5×10^{-4}
BEARINGS, TURBINE END	2.3×10^7	2.1×10^6	1.1×10^{10}	5.9×10^{11}	1.3×10^{14}	3.4	9.9×10^{-5}

Table 3

Comparison of NERVA and ASTR - 901
Test Environments

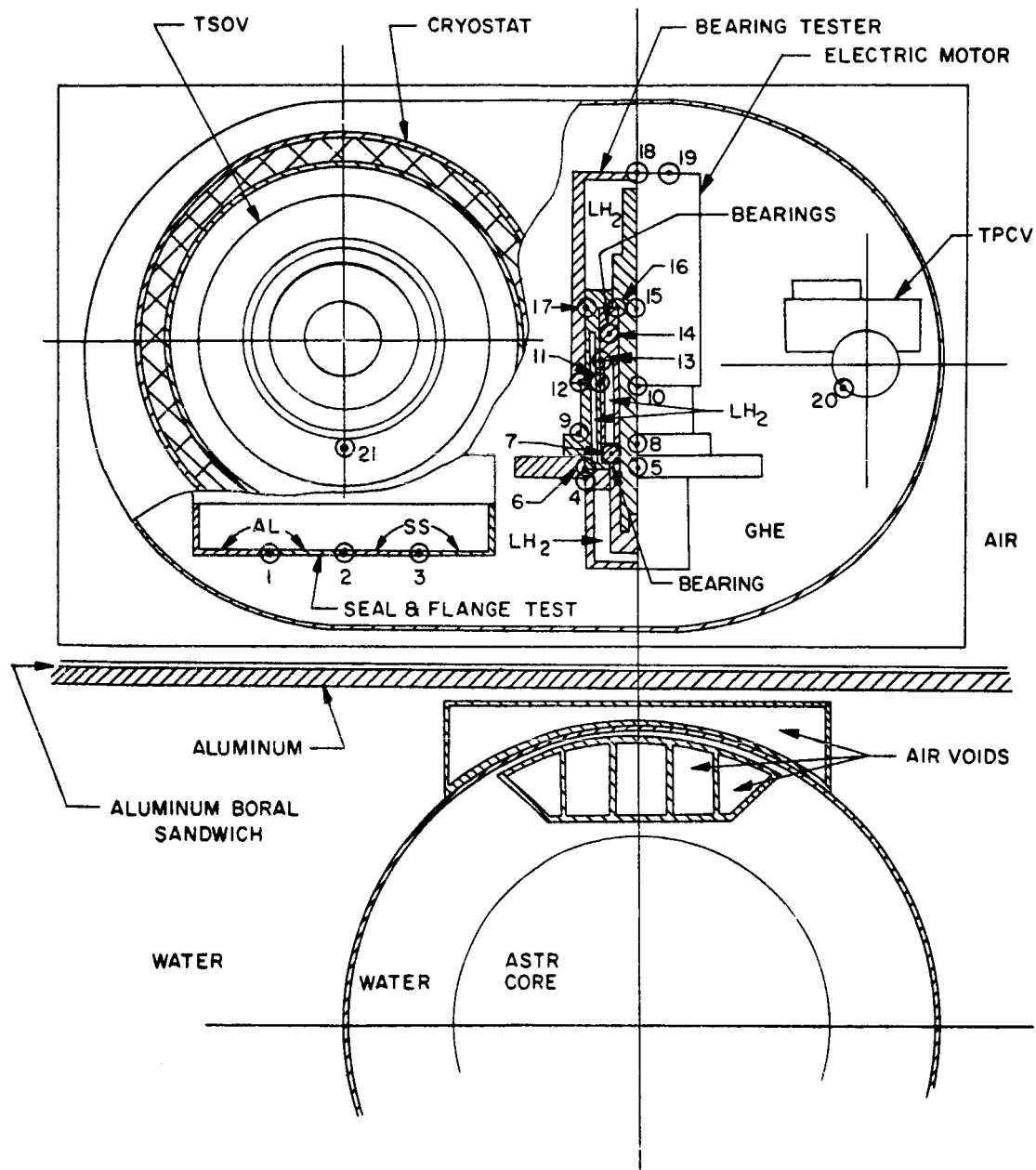


Figure 16

Dose Point Location for MIT 901

B. MIT-902

Table 4 is essentially repeated for the bearing tester configuration tested in MIT-902. The dose rates and neutron and gamma fluxes are not very different from similar locations in the 901 test. The run duration in this case was 300 seconds.

Comparisons are made between these calculated data and NERVA in Table 5.

This test has been completed and some comparisons are available with measured data, as given in Section VI of this report.

A. RADIATION ENVIRONMENT AND HEATING RATES FOR
MECHANICAL IRRADIATION TEST 902 (300 SEC DURATION)

DETECTOR POINT	DETECTOR LOCATION	MATERIAL AT DETECTOR LOCATION	GAMMA RAY DOSE RATE (ergs/gm(c)-hr)	INTEGRATED GAMMA RAY DOSE (ergs/gm(c))	GAMMA RAY NUMBER FLUX (γ /cm ² -sec)	FAST NEUTRON FLUX $E > 0.01$ Mev (n/cm ² -sec)	NEUTRON/GAMMA NUMBER FLUX RATIO	MAXIMUM NVT-n/cm	GAMMA RAY HEATING RATE BTU/in ² -sec
601	Reactor centerline-front face of shroud	Al 6061	3.6×10^9	3.0×10^8	1.7×10^{13}	$1.2 - 1.2 \times 10^{12}$	0.07 - 0.07	3.6×10^{14}	4.0×10^{-3}
614	Reactor centerline-front of bearing tester	SS 302	2.8×10^9	2.3×10^8	1.4×10^{13}	$8.8 - 9.8 \times 10^{11}$	0.063 - 0.07	2.9×10^{14}	9.7×10^{-3}
615	Top, center, forward end of bearing section	H Monel	1.7×10^8	1.4×10^7	8.2×10^{11}	$1.0 - 4.9 \times 10^{11}$	0.12 - 0.60	1.5×10^{14}	6.8×10^{-4}
7	Pump end bearing	SS 302	2.8×10^7	2.3×10^6	1.4×10^{11}	$0.37 - 5.6 \times 10^{11}$	0.26 - 4.0	1.7×10^{14}	1.1×10^{-4}
13	Turbine end bearing	SS 302	1.0×10^7	8.3×10^5	4.8×10^{10}	$0.097 - 3.9 \times 10^{11}$	0.20 - 8.1	1.2×10^{14}	4.0×10^{-5}
14	Turbine end bearing	SS 302	4.0×10^6	3.3×10^5	1.9×10^{10}	$0.067 - 3.7 \times 10^{11}$	0.35 - 19	1.1×10^{14}	1.6×10^{-5}
16	Turbine end bearing	SS 302	1.7×10^6	1.4×10^5	8.2×10^9	$0.040 - 3.6 \times 10^{11}$	0.49 - 44	1.1×10^{14}	6.9×10^{-6}
616 (18)	Reactor centerline - rear of bearing tester	Inconel X	1.1×10^5	9.2×10^3	5.3×10^8	$0.0042 - 2.3 \times 10^{11}$	0.79 - 430	6.9×10^{13}	5.2×10^{-7}
610	Reactor centerline-rear face of shroud	Al 6061	3.1×10^5	2.6×10^4	1.5×10^9	$0.0068 - 1.9 \times 10^{11}$	0.36 - 130	5.7×10^{13}	3.7×10^{-7}

B. RADIATION ENVIRONMENT AND HEATING RATES FOR
MECHANICAL IRRADIATION TEST 903 (600 SEC DURATION)

601	Reactor centerline-front face of shroud	Al 6061	3.6×10^9	6.0×10^8	1.7×10^{13}	$1.2 - 1.2 \times 10^{12}$	0.07 - 0.07	7.2×10^{14}	8.0×10^{-3}
614	Reactor centerline-front of bearing tester	SS 302	2.8×10^9	4.6×10^8	1.4×10^{13}	$8.8 - 9.8 \times 10^{11}$	0.063 - 0.07	5.8×10^{14}	1.9×10^{-2}
615	Top, center, forward end of bearing section	H Monel	1.7×10^8	2.8×10^7	8.2×10^{11}	$1.0 - 4.9 \times 10^{11}$	0.12 - 0.60	2.9×10^{14}	1.4×10^{-3}
7	Pump end bearing	SS 302	2.8×10^7	4.6×10^6	1.4×10^{11}	$0.37 - 5.6 \times 10^{11}$	0.26 - 4.0	3.4×10^{14}	2.2×10^{-4}
13	Turbine end bearing	SS 302	1.0×10^7	1.7×10^6	4.8×10^{10}	$0.097 - 3.9 \times 10^{11}$	0.20 - 8.1	2.3×10^{14}	8.0×10^{-5}
14	Turbine end bearing	SS 302	4.0×10^6	6.6×10^5	2.9×10^{10}	$0.067 - 3.7 \times 10^{11}$	0.35 - 19	2.2×10^{14}	3.2×10^{-5}
16	Turbine end bearing	SS 302	1.7×10^6	2.8×10^5	8.2×10^9	$0.040 - 3.6 \times 10^{11}$	0.49 - 44	2.2×10^{14}	1.4×10^{-5}
616 (18)	Reactor centerline-rear of bearing tester	Inconel X	1.1×10^5	1.8×10^4	5.3×10^8	$0.0042 - 2.3 \times 10^{11}$	0.79 - 430	1.4×10^{14}	1.0×10^{-6}
610	Reactor centerline-rear face of shroud	Al 6061	3.1×10^5	5.2×10^4	1.5×10^9	$0.0068 - 1.9 \times 10^{11}$	0.36 - 130	1.1×10^{14}	7.4×10^{-7}

C. RADIATION ENVIRONMENT AND HEATING RATES FOR
MECHANICAL IRRADIATION TEST 904 (3600 SEC DURATION)

601	Reactor centerline-front face of shroud	Al 6061	3.6×10^9	3.6×10^9	1.7×10^{13}	$1.2 - 1.2 \times 10^{12}$	0.07 - 0.07	4.3×10^{15}	4.8×10^{-2}
614	Reactor centerline-front of bearing tester	SS 302	2.8×10^9	2.8×10^9	1.4×10^{13}	$8.8 - 9.8 \times 10^{11}$	0.063 - 0.07	3.5×10^{15}	1.2×10^{-1}
615	Top, center, forward end of bearing section	H Monel	1.7×10^8	1.7×10^8	8.2×10^{11}	$1.0 - 4.9 \times 10^{11}$	0.12 - 0.60	1.8×10^{15}	8.1×10^{-3}
7	Pump end bearing	SS 302	2.8×10^7	2.8×10^7	1.4×10^{11}	$0.37 - 5.6 \times 10^{11}$	0.26 - 4.0	2.0×10^{15}	1.3×10^{-3}
13	Turbine end bearing	SS 302	1.0×10^7	1.0×10^7	4.8×10^{10}	$0.097 - 3.9 \times 10^{11}$	0.20 - 8.1	1.4×10^{15}	4.8×10^{-4}
14	Turbine end bearing	SS 302	4.0×10^6	4.0×10^6	1.9×10^{10}	$0.067 - 3.7 \times 10^{11}$	0.35 - 19	1.3×10^{15}	1.9×10^{-4}
16	Turbine end bearing	SS 302	1.7×10^6	1.7×10^6	8.2×10^9	$0.040 - 3.6 \times 10^{11}$	0.49 - 44	1.3×10^{15}	8.3×10^{-5}
616 (18)	Reactor centerline-rear of bearing tester	Inconel X	1.1×10^5	1.1×10^5	5.3×10^8	$0.0042 - 2.3 \times 10^{11}$	0.79 - 430	8.3×10^{14}	6.2×10^{-6}
610	Reactor centerline-rear face of shroud	Al 6061	3.1×10^5	3.1×10^5	1.5×10^9	$0.0068 - 1.9 \times 10^{11}$	0.36 - 130	6.8×10^{14}	4.4×10^{-6}

Table 4
Radiation Environment and Heating Rates

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TABLE 5

COMPARISON OF NERVA AND ASTR ENVIRONMENT
AT THE TURBOPUMP BEARING LOCATIONS

MIT Test/Bearings	Maximum γ - Dose Rate (ergs/gm(c)-hr)	Maximum γ -Dose (ergs/gm(c))	Maximum γ -Flux (γ /cm ² -sec)	Maximum n-flux $E > 0.01$ Mev (n/cm ² -sec)	Maximum nvt (n/cm ²)	Maximum n/ γ Flux Ratio	Maximum Gamma Heating Rate btu/in ² -sec
901: (1) Pump End	2.3×10^7	2.3×10^6	3.7×10^{11}	5.6×10^{11}	1.8×10^{14}	0.64	6.7×10^{-4}
Turbine End	1.6×10^7	1.4×10^6	7.8×10^{10}	3.9×10^{11}	1.3×10^{14}	5.0	6.3×10^{-5}
902: (2) Pump End	2.8×10^7	2.3×10^6	1.4×10^{11}	5.6×10^{11}	1.7×10^{14}	4	1.1×10^{-4}
Turbine End	4.0×10^6	3.3×10^5	1.9×10^{10}	3.7×10^{11}	1.1×10^{14}	19	1.6×10^{-5}
903: (3) Pump End	2.3×10^7	4.6×10^6	1.4×10^{11}	5.6×10^{11}	3.4×10^{14}	4	2.2×10^{-4}
Turbine End	4.0×10^6	6.6×10^5	1.9×10^{10}	3.7×10^{11}	2.0×10^{14}	19	3.2×10^{-5}
904: (4) Pump End	2.8×10^7	2.8×10^7	1.4×10^{11}	5.6×10^{11}	2.0×10^{15}	4	1.3×10^{-3}
Turbine End	4.0×10^6	4.0×10^7	1.9×10^{10}	3.7×10^{11}	1.3×10^{15}	19	1.9×10^{-4}
NERVA (5) Pump End	1.1×10^7	3.7×10^9	5.4×10^{10}	1.0×10^{11}	1.2×10^{14}	2.9	5.9×10^{-5}
Turbine End	1.4×10^8	4.7×10^7	4.3×10^{11}	1.0×10^{11}	1.2×10^{14}	0.23	7.5×10^{-4}

- (1) Integrated doses and nvt based on 327 second run duration.
 (2) Integrated doses and nvt based on 300 second run duration.
 (3) Integrated doses and nvt based on 600 second run duration.
 (4) Integrated doses and nvt based on 3,600 second run duration.
 (5) Integrated doses and nvt based on full duration run (1200 seconds).

Table 5

Comparison of NERVA and ASTR Environment
of the Turbopump Bearing Locations

C. MIT-903

The calculated results for MIT-903 are presented in Table 4, and are compared with NERVA values in Table 5. The difference between 902 and 903 results is the fact that the 903 test was actually run for 600 seconds whereas 902 was run for 300 seconds. The integrated doses and nvt values therefore are two times those of the 902 test.

D. MIT-904

MIT-904 is currently planned to run for 3,600 seconds (Reference 9). From a radiation level standpoint, this is the only significant planned change from 902 and 903. Radiation intensities for this test are presented in Tables 4 and 5 and are simply the 902 values increased from 300 second run duration to a 3,600 value.

Tables 3 and 5 indicate that in some cases (such as TSOV in 901) the test environment essentially mocked-up the NERVA condition, especially as regards the effects of integrated exposure. However, Table 5 shows that the bearing sets have not been exposed to integrated doses comparable to NERVA during MIT-901, 902, and 903. If a 3,600 second run can be accomplished in the 904 test, the pump-end bearings would receive double the integrated gamma dose they might receive in NERVA and the turbine-end bearings would be exposed to roughly 4% of their comparable NERVA environment for a 3,600-second 904 configuration run.

It should be remembered however, that the calculated values reported here are expected to be slightly lower than measured values if measurements could be made at the locations in question.

VI COMPARISONS WITH EXPERIMENTAL RESULTS

VI. COMPARISONS WITH EXPERIMENTAL RESULTS

A number of radiation measurements have been made during the 901, 902 and 903 tests (References 2, 3, and 4). Most of these detector locations are not related to the NERVA components being tested. However, several points were located such that a comparison between these measurements and calculated values is desirable. Such a comparison of integrated gamma doses is presented in Table 6. The last column of this table shows how much the calculated value is above or below the measurement.

In interpreting these data it is important to remember that the measured results are not absolute, but actually have a fair degree of uncertainty due to counting statistics. For example, the dose point located at the reactor-end of the bearing tester was measured to be 1.6×10^8 ergs/gm(c) in test 902 for a 300 second exposure but was reported as 1.1×10^8 ergs/gm(c) in test 903 when the exposure time was doubled. That is to say, the exposure time was doubled but the integrated dose was reduced at the same location in each test. This is pointed out to indicate the fact that inconsistencies exist in experimental data and is calculated-to-measured ratios which vary greatly from unity and which must be interpreted in this light, as well as considering analytical shortcomings. In the specific case mentioned previously, the calculated-to-measured ratio was 1.4 for the 300 second 902 test and 4.2 for the 600 second 903 test. It is the opinion of this report that the 902 test measurement is the more nearly correct value.

If the single point described is discarded (that is, the 4.2 measured-to-calculated value for 903), the spread of the calculations ranges from +90% to -67% of the measured values, with the exception of the dose point at the extreme end of the bearing tester where scattering effects (not included in the calculation) result in a calculated to measured ratio of 0.01. Other calculations, not reported herein, show that scattering is even more acute a problem in specific locations behind the test equipment.

In general, the calculations agree quite well with the measured results. In those areas where there are disagreements, reasons for the disagreements are obvious.

TABLE 6
COMPARISON OF CALCULATED AND EXPERIMENTAL DATA

TEST NUMBER	DETECTOR LOCATION	CALCULATED GAMMA RAY DOSE - ergs/gm(c)	MEASURED DOSE ergs/gm(c)	CALCULATED/ MEASURED RATIO
901	Static flange and seal test - side nearest reactor, flange farthest from reactor center line	7.1×10^7	8.1×10^7	0.88
	Static flange and seal test - side nearest reactor, flange nearest reactor center line	1.6×10^8	1.3×10^8	1.2
	Turbine power control valve - side nearest reactor	1.0×10^8	8.1×10^7	1.2
	615 Bearing tester - top, center, forward end of bearing housing	1.6×10^7	5.4×10^7	0.3
	616 Bearing tester - rear end of motor on reactor centerline	7.6×10^4	7.0×10^6	0.01
902	601 Shroud - on reactor centerline, face nearest to reactor	3.0×10^8	2.7×10^8	1.1
	614 Bearing tester - on reactor centerline, end nearest to reactor	2.3×10^8	1.6×10^8	1.4
	615 Bearing tester - top, center, forward end of bearing housing	1.4×10^7	2.1×10^7	0.67
903	601 Shroud - on reactor centerline, face nearest to reactor	6.0×10^8	3.2×10^8	1.9
	614 Bearing tester - on reactor centerline, end nearest to reactor	4.6×10^8	1.1×10^8	4.2
	615 Bearing tester - top, center, forward end of bearing housing	2.8×10^7	5.9×10^7	0.47

Table 6
Comparison of Calculated and Experimental Data

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Measured neutron data were not obtained with Plutonium threshold or Indium detecting foils ($E > 0.01$ Mev and $E > 0.85$ Mev). For this reason comparisons of neutron fluxes have not been reported here.

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